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Cost and Performance Report

(PP-9912)

Alternatives to Solvent-Based Ink and Paint Stenciling for Identification Markings

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LIST OF ACRONYMS

A/E	Aramid/Epoxy Laminate
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AL2	Aluminum Alloy 6061-T6, (QQ-A-250/11)
C/E	Carbon/Epoxy Laminate
CAA	Clean Air Act
CAR	Chemical Agent Resistance
CTC	Concurrent Technologies Corporation
DoD	Department of Defense
ECA	Environmental Cost Analysis
ESTCP	Environmental Security Technology Certification Program
FOD	Foreign Object Damage
G/E	Glass/Epoxy Laminate
HAP	Hazardous Air Pollutant
HazMat	Hazardous Material
ID	Identification
IR	Infrared Reflectance
JG-PP	Joint Group on Pollution Prevention
JTP	Joint Test Protocol
JTR	Joint Test Report
LM	Lockheed Martin
NADEP JAX	Naval Aviation Depot, Jacksonville
NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NDCEE	National Defense Center for Environmental Excellence
NNSY	Norfolk Naval Shipyard
NR	Neoprene Rubber, (AMS 3208)
NT	Not Tested
OEM	Original Equipment Manufacturer
PAR	Potential Alternatives Report
RCRA	Resource Conservation and Recovery Act

LIST OF ACRONYMS (continued)

SR	Silicone Rubber, (AMS 3347)
SS	Stainless Steel 302, (ASTM-A-240)
TTP	Thermal Transfer Printing
TYAD	Tobyhanna Army Depot
UV	Ultraviolet
VOC	Volatile Organic Compound

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Mike Romanelli, Naval Aviation Depot, Jacksonville, Florida
Jim McCarty, Norfolk Naval Shipyard, Virginia

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1.0 EXECUTIVE SUMMARY

Maintenance facilities and repair depots across the Department of Defense (DoD) use traditional marking methods to track and identify parts and components within their facilities. These traditional methods include stamping, silk-screening, and stenciling using conventional inks and paints that contain volatile organic compounds (VOC). VOC emissions are regulated by federal and state agencies as well as local air pollution control districts. As a result, those facilities that use products containing VOCs may need to obtain an emissions permit, monitor their emissions to ensure permit compliance, report their toxic chemical inventories to the U.S. Environmental Protection Agency, and monitor occupational exposure levels to ensure worker health and safety. In addition, these facilities may face waste segregation and disposal restrictions. To reduce compliance and other costs and eliminate the use of VOCs, the Environmental Security Technology Certification Program (ESTCP) and the Joint Group on Pollution Prevention (JG-PP) led a project to identify and qualify environmentally acceptable alternatives to conventional inks and paints used for identification (ID) marking.

ID marking occurs over a range of critical and noncritical applications. To denote their critical level, ID-marking applications were separated into Grades A, B, and C. Grade A is the most critical application where a removed or illegible marking affects operational and safety requirements. These markings would typically be found on the exterior of a product that is expected to be used outdoors. Grade B applications should be able to withstand the typical operating environments of electronic equipment. These markings would be found in protected environments such as inside a cabinet or indoors. Grade C applications are the least critical where a removed or illegible label does not affect operation or safety requirements. These applications involve temporary ID of chassis and parts or marking of components prior to assembly. Meeting Grade A applications qualifies the marking system for Grade B and C applications. Grade B qualified materials are not qualified for Grade A applications but can be used for Grade C. Grade C applications should not be used for Grade A or Grade B applications.

Potential alternatives to conventional stenciling materials include ultraviolet (UV), curable low-VOC inks, water-soluble inks, and various types of label material. Nine inks and 10 label systems were selected to undergo validation testing. The selected alternatives were tested according to a Joint Test Protocol (JTP)[1] developed with input from a stakeholder group assembled from across the DoD. All alternatives were tested in according to the JTP for Phase I screen parameters and, on passing Phase I requirements, were further tested according to Phase II extended parameters.

ID marking occurs on both bare and painted substrates that may be used in a variety of environments ranging from hot and humid to cold and dry. For this reason, testing of each alternative included evaluating the performance on bare substrates and substrates containing a common DoD primer and topcoat. These substrates were subjected to several tests including adhesion, legibility, salt spray, exposure to chemicals, effects of temperature variations, infrared reflectance (IR), and chemical agent resistance (CAR).

The test data were compiled and reported in a Joint Test Report (JTR)[2] dated June 26, 2001, with recommendations on application grades for each alternative. Due to poor adhesion, the usefulness of the alternatives was limited on smooth substrates such as butyl rubber and glass/epoxy laminated

materials. Two of the alternative inks and all 10 label systems were approved for Grade A applications on at least one substrate.

Demonstration of the technologies was planned for Lockheed Martin (LM) Missiles and Fire Control and LM Information Systems Companies in Orlando, Florida; Naval Aviation Depot, Jacksonville, Florida (NADEP JAX); Tobyhanna Army Depot (TYAD), Pennsylvania; and Norfolk Naval Shipyard (NNSY), Portsmouth, Virginia. These demonstrations showed, with some limitations, that the alternatives are acceptable replacements for current ID-marking processes.

In general, current specifications address only what markings should contain, not how to apply the marking. Affected specifications at the LM Companies include MIL-STD-130, MIL-STD-129, MIL-HDBK-454 Rqmt 67, MIL-M-81531, MIL-M-87958, MIL-PRF-61002, MIL-I-43553, MIS20238, MIS19916, and MIS22043. LM has in place a single process initiative block change for ID-marking alternatives and has implemented the materials validated by this project. As a result, at least 22 DoD programs such as LANTIRN, Hellfire, Javelin, Longbow, Patriot, and Predator will be directly impacted.

A cost benefit analysis performed for two separate facilities showed that the savings will vary depending on which alternative is implemented. At the NADEP JAX facility, an annual cost saving of $58,000 resulted when a labor-intensive identification marking process (silk-screening) was replaced with thermal transfer printed self-adhesive labels. Although a capital expenditure of $15,500 is required every 5 years to replace the printer, computer, monitor, and software, the reduced labor cost makes thermal transfer printed labels an attractive option. Implementing an ink alternative at a second facility showed no reduction in labor and an increase in operating costs due to the higher cost of the ink. This drop in replacement for spray stenciling with paint may be an option for a facility that is required to reduce VOC emission to meet environmental compliance.

2.0 TECHNOLOGY DESCRIPTION

Stenciling, silk-screening and stamping are currently used throughout the DoD to mark electronics cabinets and cabinet parts; aluminum, steel, and stainless steel sheets and parts; nonmetallic materials; painted metal surfaces; and elastomers. Since current inks and paints used for marking have a high VOC content, DoD stakeholders targeted them for reduction or elimination.

Several inks, including waterborne and UV-curable, were selected for consideration as alternatives to baseline inks because they can be implemented quickly and inexpensively. Self-adhesive labeling was also selected for further consideration because it has the potential to eliminate almost all environmental, safety, and occupational health impacts associated with VOC-containing inks. It also has the potential to reduce labor costs. Several types of self-adhesive labels were selected for consideration, including polyester, polyimide, polyvinyl fluoride, and metallized. These self-adhesive labels can be used with ink jet, laser, or thermal transfer printers. Both alternative inks and self-adhesive labels can be used in a paint shop/stationary setting or in the field (e.g., hand-held printers).

The major concern with ID-marking alternatives is whether the alternative adheres to the surface well enough to meet DoD's needs. Adhesion of both inks and labels may be affected by environmental factors (weathering), changes in temperature, and exposure to maintenance chemicals such as hydraulic fluids, lubricants, or solvents. Therefore, applying labels to common coatings used throughout the DoD, exposing them to common chemicals, and testing adhesion were critical components of this project.

Little or no training is required for these alternatives since the alternative ink can be used as a drop-in replacement for existing inks. The self-adhesive labels require training on the labeling software, as well as minimal training for applying the labels and using the printers. Since laser printers and DeskJet printers are used for some of the alternate labels, software programs such as CorelDraw and Adobe Illustrator can be used directly with no additional training. Training on ribbon replacement and rolled label stock installation is required for thermal transfer printing (TTP). However, the software used for TTP allows importing of graphics from other software programs such as CorelDraw, Word Art, and Adobe Illustrator, allowing personnel already familiar with current graphics programs to continue using that software to generate the label.

Health and safety requirements must be evaluated for each facility, but the requirements are expected to be reduced. The alternative inks have fewer hazardous constituents and a lower VOC content than traditional inks or paints. The labeling equipment is standard office equipment that eliminates concerns associated with conventional marking methods.

TYAD rated the alternative ink as an easy-to-use and acceptable alternative to the current paint spraying operation. NADEP JAX found that the graphics files currently used could easily be imported into the TTP software and that printing TTP labels was quick. Although NNSY received the equipment for printing thermal transfer labels, it never installed or demonstrated the alternative because its sign shop was investigating multicolor, UV-resistant ink printing on larger surfaces. The proposed alternative did not fit its operational requirements.

No additional equipment is required to implement waterborne ink alternatives. These inks dry quickly and should reduce holding time within the shop. UV inks, on the other hand, will require either a hand held lamp or the installation of a UV light source. Since they require a longer cure time, these inks may increase holding time within the shop.

Label alternatives are printed using standard office computers, monitors, and printers (laser, ink jet, or thermal transfer). Because printing labels may involve large graphic files, additional computer memory should be considered. Additional storage devices (Zip, CD-R/W or tape drive) should be considered for storage or backup to prevent loss of graphic files. Saving, sharing, and printing files over a network should be considered if several shop locations within a facility are using label alternatives. Using labels in place of silk-screening or stenciling with paint should reduce labor and holding time within the shops because fewer steps are required with labels.

One limitation of the self-adhesive label material is its failure to pass solder flux resistance testing. During soldering operations, a circuit board with a label is floated on a high temperature molten solder bath (500°F) and followed by a terpene-based solvent to remove flux. Failing this test requirement removed several label materials from Grade A applications.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

A stakeholder group was assembled with representatives from the Army, Navy, Air Force, Marine Corps, National Aeronautics and Space Administration (NASA), and Coast Guard. After a review of several available technologies, the stakeholder group selected UV-curable inks, low-VOC inks, and self-adhesive labels as the most suitable alternatives to replace the current marking processes. A list of alternative inks and label systems was selected and described in the *Potential Alternatives Report for Validation of Alternatives to Solvent-Base Ink Stenciling for Identification Marking* (PAR),[3] July 16, 1998.

The stakeholder group defined and documented the performance objectives in the *Joint Test Protocol for Validation of Alternatives to Solvent-Base Ink Stenciling for Identification Marking*, March 11, 1997. Refer to the JTP, available at the JG-PP web site, www.jgpp.com,[4] for a description of performance requirements for the alternative ID marking process. The discussion in the JTP includes a description of each validation test, the rationale for the tests, test methodologies, substrates being tested and any unique equipment, instrumentation, and data analysis. Test methodology includes the definition of test parameters, test specimens, test trials, and pass/fail criteria. To meet specific demonstration facility needs, additional objectives were added after the JTP was produced. These objectives included decreased process time and nonflammability, which was identified by the NNSY.

3.2 PHYSICAL SETUP AND OPERATION

After stakeholders approved both the JTP and Potential Alternatives Report (PAR), validation testing was performed in two phases. The results for each alternative were available for stakeholder review after each phase. Table 1 shows the test parameters for each phase of the verification of alternative inks and labels.

Table 1. Test Parameter for Each Phase of the Verification of Alternative Inks and Labels.

Phase	Part	Description
I	A	– Test baseline ink and alternative inks for adhesion to substrate. – Test baseline ink and alternative inks for legibility to substrate. – Test blank self-adhesive labels for adhesion to substrate.
	B	– Test baseline ink, alternative inks, and printed labels for salt spray. – Test blank self-adhesive labels for salt spray resistance, UV light/condensation, thermal shock, and exposure to various chemicals (isopropyl alcohol, de-ionized water, engine oil, and terpene-based solvent).
II	C	– Test alternative inks for fungus, IR, and CAR.
	D	– Test printed self-adhesive labels for adhesion and legibility.
	E	– Test baseline ink and alternative inks for corrosivity, DC electrical resistance, and exposure to chemicals (Coolanol, PAO, hydraulic fluid, lubricating oil, JP5, DS2, and Skydrol). – Test printed self-adhesive labels for corrosivity, DC electrical resistance, and exposure to chemicals (Coolanol, PAO, hydraulic fluid, lubricating oil, JP5, DS2, and Skydrol).
	F	– Test printed self-adhesive labels for fungus, IR, and CAR.

During Phase I screening tests, inks and labels were applied to bare substrate to determine whether each alternative adhered to the substrate surface. After Phase I, four alternative inks that did not meet the performance criteria established in the JTP were removed from further consideration. During Phase II, inks and labels were applied to primed and coated substrates. A list of substrates used to evaluate the alternatives is shown in Table 2.

Table 2. Test Panel Specimen Codes and Substrate Descriptions.

Panel Specimen	Substrate Descriptions
AL1a	Aluminum alloy 2024, (QQ-A-250/4), cleaned, chromate conversion coated, primed with MIL-P-23377 (to a dry film thickness of 0.8-1.2 mils), room-temperature cured for 1 to 24 hours, topcoated with MIL-C-46168 (to a dry film thickness of 1.8 mils minimum), room-temperature cured for 15 minutes, and cured at 60ºC (140 ºF) for 30 minutes. This AL1 version was used for ink and label tests.
AL1b	Aluminum alloy 2024, (QQ-A-250/4), cleaned, chromate conversion coated, primed with MIL-P-23377 (to a dry film thickness of 0.8-1.2 mils), room-temperature cured for 1 to 24 hours, topcoated with MIL-C-53039 (to a dry film thickness of 1.8 mils minimum), room-temperature cured for 4 days, and cured at 104ºC (220 ºF) for 3 days. This AL1 version was used for blank label tests only.
AL1c	Aluminum alloy 2024, (QQ-A-250/4), cleaned, chromate conversion coated, primed with MIL-P-23377 (to a dry film thickness of 0.8-1.2 mils), room-temperature cured for 1 to 24 hours, topcoated with MIL-C-85285 (to a dry film thickness of 1.8 to 2.4 mils minimum), room-temperature cured for at least 1 hour, and cured at 54 ºC (130 ºF) for 12 hours minimum. This AL1 version was used for blank label tests only.
AL1d	Aluminum alloy 2024, (QQ-A-250/4), cleaned, chromate conversion coated, primed with MIL-P-85582 (to a dry film thickness of 0.6-0.9 mils), room-temperature cured for 1 to 18 hours, topcoated with MIL-C-85285 (to a dry film thickness of 1.8 to 2.4 mils minimum), room-temperature cured for at least 1 hour, and cured at 54 ºC (130 ºF) for 12 hours minimum. This AL1 version was used for blank label tests only.
AL1e	Aluminum alloy 2024, (QQ-A-250/4), cleaned, chromate conversion coated, primed with MIL-P-85582 (to a dry film thickness of 0.6-0.9 mils), room-temperature cured for 1 to 18 hours, topcoated with MIL-C-22750 (to a dry film thickness of 0.8-2.0 mils), room-temperature cured for at least 20 minutes, and cured at 54 ºC (130 ºF) for 20 minutes minimum. This AL1 version was used for blank label tests only.
AL2	Aluminum alloy, 6061-T6, (QQ-A-250/11), cleaned and chromate conversion coated in accordance with MIL-C-5541.
SS	Stainless steel 302, (ASTM-A-240), cleaned.
NR	Neoprene rubber, (AMS 3208), scuffed to remove mold release or other foreign coating, and cleaned by wiping with acetone per O-A-51.
SR	Silicone rubber, (AMS 3347), cured at 204ºC (400 ºF) for 4 hours, scuffed to remove mold release or other foreign coating, and cleaned by wiping with acetone per O-A.
G/E	Glass/epoxy laminate, either custom fabricated in a suitable laboratory or purchased from a material supplier [*custom fabricated with DuPont N4000-6 epoxy prepreg and cured in a press for 90 minutes at approximately 250 psi and 182 ºC (360 ºF)*], and cleaned by solvent wiping with alcohol per TT-I-735A.

Table 2. Test Panel Specimen Codes and Substrate Descriptions. (continued)

Panel Specimen	Substrate Descriptions
C/E	Carbon/epoxy laminate, either custom fabricated in a suitable laboratory facility or purchased from a material supplier [*custom fabricated with Fiberite MXG7620-2534 prepreg and vacuum bagged and cured in an autoclave at 100 psi and 93 ºC (200 ºF) for 4 hours*], and cleaned by solvent wiping with acetone per O-A-51.
A/E	Aramid/Epoxy Laminate, (MIL-S-13949/15), unclad, either custom fabricated in a suitable laboratory facility or purchased from a material supplier [*custom fabricated with DuPont N4500-6T Thermount epoxy prepreg and cured in a press for 90 minutes at approximately 300 psi and 182 ºC (360 ºF)*], and cleaned by solvent wiping with acetone per O-A-51.

After Phase II, each alternative was assigned an application grade (A, B or C), depending on how the test results compared to the performance objectives. Using the results of validation testing, the most suitable alternatives for NADEP JAX, TYAD, and NNSY were selected for demonstration. Each demonstration site was evaluated to determine the appropriate equipment setup, utility (electrical) connections, and other services necessary to complete the implementation.

3.3 MEASUREMENT OF PERFORMANCE

Each alternative was tested according to the requirements of the JTP and the results were presented in the *Joint Test Report for Validation of Alternatives to Solvent-Based Ink Stenciling for Identification Marking*, June 26, 2001. Based on the test results, an application grade of Class A, B, or C was assigned to each alternative and substrate/primer/topcoat combination. Refer to the JTR, available at www.jgpp.com, for the test results for each alternative.

Performance during implementation was measured by distributing questionnaires to users of the alternative inks and labels. The questionnaires addressed applications on which the alternatives were used, ease of use, appearance, and future monitoring of the labels. NNSY and TYAD reported regularly on the usability of these materials. Performance assessment methods are described in detail in the JTP. Other parameters, such as hazardous materials (HazMat), process waste, usability, reliability, versatility, maintenance, and scale-up issues were monitored.

3.4 DEMONSTRATION SITE/FACILITY BACKGROUND AND CHARACTERISTICS

Although demonstrations were planned for four facilities (LM Orlando, NADEP JAX, TYAD, and NNSY), only three occurred. At LM Orlando, labels were implemented, but no cost-saving data was collected. TYAD used inks for stenciling in place of paint. NADEP JAX used alternative labels in place of silk-screening.

Lockheed Martin (LM) Missiles and Fire Control in Orlando, Florida, is the corporation's lead business unit for research, development, and production of electro-optic and smart munitions systems. Employing 3,750 people, LM Missiles and Fire Control develops, manufactures, and supports advanced combat systems such as missile, rocket, and space systems for the U.S. Army, Navy, Air Force, and Marine Corps. LM also provides systems to foreign nations approved by the U.S. Department of State. The Missile and Fire Control companies are pioneers in developing

electronics packages for imaging, signal processing, and large system integration. The Information Systems Company provides advanced data storage, imaging, and communications systems to military clients.

At the LM Orlando site, VOCs such as methyl ethyl ketone and toluene found in epoxy resin-based inks were identified as the target HazMats to be eliminated or reduced. These inks are used to stencil or stamp mechanical hardware and electronic components that are used in a broad spectrum of applications. Parts to be labeled include circuit boards prior to soldering, components that are exposed to oils and greases in engine rooms, assemblies inside cabinets that may be wiped with alcohol for cleaning, and parts that are repaired in shops and are thus exposed to flux removers, solvents, and fuels. The surfaces to be labeled may be bare or painted metallics or nonmetallics.

Tobyhanna Army Depot (TYAD), the largest full-scale communications-electronics maintenance facility in the DoD, employs approximately 3,000 employees with electronics, engineering, and logistical expertise. The Depot's mission includes the design, manufacture, repair, and overhaul of communications and electronics systems. Communications-electronics systems supported by TYAD include communications, command and control, surveillance and target acquisition, airborne electronics, intelligence and electronic warfare, electronic support equipment, and powder systems.

Costs for the current ID marking process are primarily for labor, followed by waste management, materials, and utilities. For ID marking, TYAD uses epoxies for interior applications and polyurethane for exterior applications.

Environmental concerns at TYAD include constituents listed as hazardous air pollutants (HAP) under the Clean Air Act (CAA), as amended in 1990, and sludge that must be disposed of as hazardous waste under the Resource Conservation and Recovery Act (RCRA). Several health concerns are associated with constituents that are carcinogens, teretogens, genotoxicants, and neurotoxicants. No additional licenses or permits are necessary to implement the alternatives. However, TYAD requires approval from the Army Research Laboratory before implementing an alternative.

Naval Aviation Depot Jacksonville (NADEP JAX) in Jacksonville, Florida, is one of three modern industrial facilities commissioned by the Navy to perform in-depth rework, repair, and modification of aircraft, engines, and aeronautical components. Aircraft such as P-3 (Orion - Antisubmarine Patrol Plane), T-2 (Buckeye - Basic Jet Trainer), F/A-18 (Hornet - Strike Fighter), and A-7 (Corsair - Light Attack Carrier-Based Jet Bomber) come to the depot for maintenance, repair, conversion, or modernization. The Depot also maintains a state-of-the-art engine facility for rework and repair of aircraft engine components, assemblies, and accessories for the J-52 (A-4 and A-6 aircraft engine), TF-41 (A-7 aircraft engine), and F-404 (F/A-18 aircraft engine). An estimated one-third of the workload within the Depot consists of large and small electrical or mechanical components that make up an aircraft, engine, or weapon system.

A large portion of the ID marking within the Graphic Arts Shop consists of preparing inspection stickers, equipment labels, and warning signs on vinyl material using a silk-screening process. Cost for the current ID marking process consists primarily of labor required to produce these labels.

Environmental concerns at NADEP JAX include constituents listed as HAPs under the CAA, cleaning solvent and solvent-soaked rags, and sludge that must be disposed of as hazardous waste under RCRA. As with TYAD, health concerns include constituents that are carcinogens, teretogens, genotoxicants, and neurotoxicants. No additional licenses or permits were necessary to implement the alternatives. However, NADEP JAX must obtain Naval Sea Systems Command (NAVSEA) approval prior to implementation.

Norfolk Naval Shipyard (NNSY) in Portsmouth, Virginia, is one of the largest shipyards in the world. NNSY specializes in repairing, overhauling, and modernizing ships and submarines. It also performs technical work, fabrication, manufacturing, and engineering. NNSY has 17 production shops in 69 production shop buildings. Some production shops include the Forge Shop, Welding Shop, Pipe Shop, and Paint Shop. The Paint Shop/Sign Shop was the focus for this demonstration. The Paint Shop, referred to as Shop 71, performs abrasive blasting of ships' hulls and various types of painting on ships, including ID marking.

NNSY performs extensive paint stenciling on a variety of equipment and applications, including wires, bulkheads, engines and machinery, and electronic equipment. Costs for the current ID marking process are primarily for labor, followed by waste management, materials, and utilities. Guidance for ID markings focuses on the location, size, and color of marking, as compared to performance requirements. However, many items at the shipyard, including machinery and bulkheads, must withstand heat, cleaning solutions and chemicals, and fire fighting agents. Enamels are typically used for ID marking at NNSY. Limited ink stenciling is performed within the torpedo group at the shipyard.

Environmental concerns at NNSY include constituents listed as HAPs under the CAA and sludge that must be disposed of as hazardous waste under RCRA. Additional health concerns include constituents that are carcinogens, teretogens, genotoxicants, and neurotoxicants. No further licenses or permits would be required to implement the alternatives at this site. NAVSEA approval would also be required at NNSY before alternatives could be implemented.

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4.0 PERFORMANCE ASSESSMENT

The objective of this demonstration was to identify acceptable alternatives through extensive laboratory testing. No significant deviations from the procedures outlined in the JTP occurred during validation testing. Minor deviations are described in detail in the JTR.

All of the data collected were included in both the ESTCP final report [6] and JTR and were used to evaluate and validate each alternative. Some ink alternatives were removed from further testing early in the validation process because they failed to meet the screening criteria. Two alternative inks were validated for Class A applications on several substrates. All label systems were validated for Class A applications on at least one substrate/coating. After evaluating the test results for the performance of each alternative on each substrate/coating combination, a Class A, B or C application rating was assigned. The classification of all inks tested can be found in Table 3.

Table 3. Alternative Inks and Application Grades.

Technology	Alternative	Substrate[1]							
		AL1a	AL2	SS	NR	SR	G/E	C/E	A/E
Baseline Ink	ACMI $6,051 Ink	A, B, C	NT	NT	NT	NT	A, B, C	NT	NT
UV-Curable Ink	80 Series UV-Curable Ink	C	None	None	None	None	None	C	None
	MSK-Series UV-Curable Ink[2]	None	None	None	None	None	None	None	None
	UV3004[2]	None	None	None	None	NT	None	None	None
Waterborne Ink	AERO No. 6565	C	None	None	None	NT	None	None	None
	CS7-56 Water-Based Ink	C	None	None	None	NT	None	None	None
	DPI #311	A, B, C	A, B	A, B, C	C	NT	None	A, B, C	None
	WB 2040M[2]	None	None	None	None	NT	None	None	None
	WB82[2]	None	None	None	None	NT	None	None	None
	Willmark #44	A, B, C	C	C	C	NT	None	C	C

[1] Only common results are summarized in this table.
[2] Removed from consideration after initial screening tests.
NT = Not tested.

The classification for each label can be found in Tables 4 and 5. Table 4 provides the application grades assigned to aluminum substrates that were primed and painted according to the specification given in Table 2. Table 5 provides the application grades for the remaining nonaluminum substrates.

Table 4. Application Grades for Self-Adhesive Labels on Aluminum-Based Substrates.

Name	Printer Technology	Substrate[1,2]					
		AL1a	AL1b	AL1c	AL1d	AL1e	AL2
Brady B-107 Matte White Polyester	Ink Jet	C	A, B, C	A, B, C	A, B, C	A, B, C	C
Brady B-423 Thermal Transfer Printable Glossy White Polyester Label Stock	Thermal Transfer	C	A, B, C	A, B, C	A, B, C	A, B, C	C
Brady B-437 Thermal Transfer Printable Label Stock	Thermal Transfer	C	A, B, C	A, B, C	A, B, C	A, B, C	A, B, C
Brady B-652 Printable High Temperature Label Stock	Laser	C	A, B, C	A, B, C	A, B, C	A, B, C	C
Brady B-747 Lasertab Markers	Laser	C	A, B, C	A, B, C	A, B, C	A, B, C	C
Critchley Clear Polyester (TTP200CL-10)	Thermal Transfer	C	None	A, B, C	A, B, C	A, B, C	C
Critchley Metallized Thermal Transfer (CR-104-MP)	Thermal Transfer	C	A, B, C	A, B, C	A, B, C	A, B, C	C
Critchley White Polyester Film (CR-119-CP2.5)	Thermal Transfer	C	A, B, C	A, B, C	A, B, C	A, B, C	C
Tyton 822	Thermal Transfer	C	A, B, C	A, B, C	A, B, C	A, B, C	C
Tyton 900	Thermal Transfer	None	A, B, C	A, B, C	A, B, C	A, B, C	C

1 Only common results for blank and printed labels are summarized in this table.
2 If solder float/terpene-based solvent chemical exposure results are disregarded, all Class C applications in this table change to Class A, B, or C applications.

To select an appropriate alternative, users need to identify the appropriate combination of substrate, primer, and topcoat and determine the application (Class A, B, or C).

Table 5. Application Grades for Self-Adhesive Labels on Non-Aluminum Substrates.

Name	Printer Technology	Substrate[1,2]					
		SS	NR	SR	G/E	C/E	A/E
Brady B-107 Matte White Polyester	Ink Jet	C	C	None	C	C	C
Brady B-423 Thermal Transfer Printable Glossy White	Thermal Transfer	C	None	C	C	C	C
Brady B-437 Thermal Transfer Printable Label Stock	Thermal Transfer	C	C	None	C	C	C
Brady B-652 Printable High Temperature Label Stock	Laser	A, B, C	None	None	None	A, B, C	A, B, C
Brady B-747 Lasertab Markers	Laser	C	C	None	C	C	C
Critchley Clear Polyester (TTP200CL-10)	Thermal Transfer	C	None	None	C	C	C
Critchley Metallized Thermal Transfer (CR-104-MP)	Thermal Transfer	C	C	None	C	C	C
Critchley White Polyester Film (CR-119-CP2.5)	Thermal Transfer	C	C	None	C	C	C
Tyton 822	Thermal Transfer	C	C	None	C	C	C
Tyton 900	Thermal Transfer	None	C	None	C	C	C

1 Only common results for blank and printed labels are summarized in this table.
2 If solder float/terpene-based solvent chemical exposure results are disregarded, all Class C applications in this table change to Class A, B, or C.

When validation testing was complete, the demonstration facilities selected alternatives to demonstrate within their respective shops. LM implemented label systems within the facilities in Orlando, but no cost data was collected for this demonstration. TYAD, which uses epoxy and polyurethane coatings of various colors to stencil part numbers and identification numbers onto camouflaged surfaces, chose a low VOC ink alternative, Dell DPI#311, to demonstrate. NADEP JAX selected thermal transfer labeling for equipment inspection stickers, temporary part labeling, and miscellaneous signage within the shop area. Cost data was also provided by NADEP JAX to compare silk-screening costs with thermal transfer labeling. NNSY chose a low VOC ink alternative and several thermal transfer label systems to demonstrate. The timing of this demonstration conflicted with other shop activities and no demonstration was conducted at NNSY.

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5.0 COST ASSESSMENT

The cost assessment was based on the Environmental Cost Analysis (ECA^{SM}) Methodology described in the *Environmental Cost Analysis Methodology Handbook*, [5] March 29, 1999.

There are three scenarios for implementing ID-marking alternatives: inks can be used for stenciling in place of paint as demonstrated at TYAD, alternative labels can be used in place of silk-screening as demonstrated at NADEP JAX, or labels can be used instead of stenciling with paint. This technology has been implemented at LM Orlando, but cost-saving data are not available. None of the demonstration facilities had a need to use labels in place of stenciling, as most applications consisted of part numbering on camouflaged or low-reflective surfaces. Consequently, a white, metallic, or shiny label material substitute was unacceptable.

Life-cycle costs were estimated based on the demonstrations performed at two DoD locations: TYAD and NADEP JAX. The cost assessment indicates that little to no savings are realized by replacing paint with ink. Replacing silk-screening with labels, however, will result in significant savings. The payback period for implementing thermal transfer printed labels over silk-screening is approximately 6 months.

CASE 1: Tobyhanna Army Depot (TYAD) Ink Stenciling Demonstration

The alternative demonstrated at TYAD was an ink that can be reduced and cleaned using water. Initially, a cost savings was anticipated due to reduced solvent use for cleaning both stencil material and the spray gun as well as eliminating the solvent used to reduce the paint. However, trials conducted at the Depot revealed that solvent was required to remove the dry ink from the stencil since water did not remove the ink. Solvent was also required for cleaning the spray gun. Consequently, the only cost difference between the paint and ink is the cost variation between the material prices. The annual paint cost at the Depot is approximately $770 per year while the cost for replacing all paint used with ink is approximately $1,500 per year.

The following observations can be made concerning the demonstration conducted at TYAD.

- Overall VOC usage would decrease, but environmental monitoring would not be reduced as the shop will continue to use paint for stenciling other colors.

- Cleaning solvent cost would not be reduced because paint stenciling is still used within the shop. Solvent pick-up/recovery is performed by a vendor on a monthly schedule and will continue.

- Waste generation/disposal would not be reduced as rags and paper stencils would still be used and disposed as paint waste.

In summary, switching to the ink alternative would not be a cost driver for TYAD but may be valuable for environmental compliance issues by reducing VOC usage.

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^{SM} is a service mark of Concurrent Technologies Corporation (CTC), Johnstown, Pennsylvania.

CASE 2: Naval Aviation Depot Thermal Transfer Labeling Demonstration

The alternative demonstrated at NADEP JAX was a thin polyester film (available in white and clear) with adhesive backing, which comes on a 100-foot roll. A 900-foot roll of thermal transfer ribbon with black ink is used for TTP onto the polyester film. An estimated 50% of the silk-screening load can be replaced with TTP using the black ribbon and white or clear polyester film.

A number of printing applications within the graphic arts shop include silk-screening with red ink on white material, white ink on red material, black ink on yellow material, and red ink on yellow material. The shop also performs a printing process on metal foil using photographic chemicals, developer, and solvent. The metal foil ranges from thin (0.003-inch thick) to about 1/8-inch thick. The metallized polyester material can be used to replace labeling applications where the thin metal foil is used. By providing the shop with yellow polyester film, metallized polyester film, and red TTP ribbon, an additional 25% of the workload can be transitioned.

Equipment costs for TTP consist of the purchase of a thermal transfer printer, computer, monitor, and associated software. The vendor, as part of the equipment purchase, will install the equipment; however, start-up labor is required for training the operators, the amount depending on the operator's skill with the graphics software. Additional training may be required for graphics software such as CorelDraw or Adobe Illustrator.

Material costs for silk-screening include clear material for preparing a negative image, silk screen film, developer, cleaning solvent, vinyl label stock, and silk-screening ink. Material costs for implementing labels compared to using vinyl material include thermal transfer ribbon and polyester label stock. Labor costs for silk-screening include preparing chemical solutions, preparing the screen, creating the marking, and cleanup. In addition, a large amount of time is spent handling, transporting, and disposing of waste material. Table 6 shows the cost savings associated with transitioning 50% of the silk-screening applications (Scenario 1) with TTP, and the cost associated with transitioning 75% of the silk-screening applications (Scenario 2) using additional colored label stock and colored ribbon. The projections indicate that implementing TTP will reduce most of the labor cost associated with the current process.

Table 6. Impact of TTP on the Cost of Silk-Screening at NADEP JAX.

Cost Element	Current Operation	Scenario 1 50% Transition	Scenario 2 75% Transition
Capital Costs			
Equipment	$0	$14,500	$14,500
Installation	$0	$0	$0
Start-up	$0	$1,040	$1,040
Total Capital Costs	**$0**	**$15,540**	**$15,540**
Annual Operating Costs			
Silk Screen Film	$900	$450	$225
Miscellaneous (Chemicals, Solvent, Cloth)	$2,642	$1,356	$660
Ink	$286	$185	$72
Vinyl (White and Clear)	$12,133	$6,067	$3,033
Vinyl (Yellow)	$14,080	$14,080	$3,520
Metal Foil	$1,123	$1,123	$0
Label Material	$0	$4,255	$19,350
Ribbon Material	$0	$7,333	$14,400
Total Operating Costs	**$31,164**	**$34,849**	**$41,260**
Annual Labor Costs			
White/Black Decals	$35,662	$11,822	$11,822
Color Decals	$35,661	$35,308	$23,565
Metal Foil Decals	$15,438	$15,438	$2,438
Miscellaneous Labor	$19,435	$9,718	$4,859
Total Labor Costs	**$106,196**	**$72,286**	**$42,684**
Environmental Costs			
Waste Disposal	$3,792	$1,896	$944
Compliance	$1,969	$1,125	$303
Total Environmental Costs	**$5,761**	**$3,021**	**$1,247**
Total Cost	**$143,121**	**$125,696**	**$100,731**

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

No significant cost savings is seen with implementing ink stenciling in place of paint stenciling. However, when thermal transfer labels were used in place of silk-screening, a significant cost savings was seen is due largely to eliminating the labor cost associated with creating the silk-screen and producing the marking.

Tobyhanna Army Depot (TYAD)

No cost reduction is shown by using inks to replace paint stenciling. The material cost of the ink is about twice that of epoxy and polyurethane paint. No reduction of environmental activities is seen because primers, topcoats, and solvents are still used within the shop. These materials will still require monitoring and reporting. Minimal reduction in waste disposal is shown because waste will still be handled since hazardous paint waste, primers, and topcoats are still used. Solvent will still be used to clean the stencils and spray guns.

Naval Aviation Depot Jacksonville (NADEP JAX)

Table 6 shows a capital investment of $15,540 in the first year. The assumption is that the printer, computer, monitor, and software will be replaced every 5 years. This capital investment will be paid back in the first 6 months after implementation. If this facility transitioned 50% of the work to label alternatives, a savings of approximately $17,000 should result in the first year. By transitioning 75%, a savings of approximately $42,000 should occur. In years 2 through 5, without the capital cost, an annual savings of approximately $33,000 (for 50% transition) and $58,000 (75% transition) should result. Although material costs are expected to rise, replacing silk-screening, a labor-intensive activity, with label alternatives provides a cost savings because of the significant labor reduction.

6.2 PERFORMANCE OBSERVATIONS

The project began by first creating a JTP and a PAR, in which alternatives were identified and selected. Next, all the alternatives were evaluated based on criteria provided in the JTP. Those alternatives that failed to pass the performance criteria were removed from further testing. Candidates that met requirements were considered for implementation at the four selected DoD locations. Implementation was used to further validate that the alternatives would meet real-life applications.

TYAD uses several different color coatings to stencil ID numbers onto camouflaged enclosures. For visibility reasons, stencil colors are chosen to contrast with the product's base color. For example, black may be used on brown, tan, gray, or green topcoat while brown may be used on tan, gray, or green topcoat. However, the ink that was used at TYAD was black, and no other colors were available that met the requirement of the military specification. Although the Dell Ink #311 was validated during laboratory testing and performed well after outdoor exposure for more than 1 year, the ink was easily removed when wiped with acetone. This issue, which was not addressed in the JTP, led TYAD and LM Orlando to remove the ink from consideration as an alternative.

LM Orlando implemented all of the label materials validated in this project to mark cabinets, chassis, enclosures, and parts prior to assembly. The label materials have performed well with no reports of problems associated with their use.

NADEP JAX implemented TTP on polyester materials. These labels performed well when used as a replacement of the current materials. One limitation of the TTP labeling is the lack of availability of different colored label materials. NADEP JAX uses vinyl stock in blue, green, yellow, pink, and white for inspection stickers. White on red and red on white are also frequently used as are black on yellow and red on yellow. The lack of colored material that met the military specification is also a limitation of the label material.

6.3 OTHER SIGNIFICANT OBSERVATIONS

The thermal transfer printer provides for only one color ink to be printed on one color background label. The extent of implementation will depend on the availability of labels and ribbons of the appropriate color. For this demonstration, white, clear, yellow, and metallized labels were provided along with black and red ribbon. These combinations permitted transitioning about 75% of the current work away from silk-screening. Silk-screening and printing on metal foil will still be required to accomplish the remaining 25% of the projects performed by the shop.

6.4 END-USER/OEM ISSUES

The reflective properties of some of the label materials caused concern for some facilities identifying exterior surfaces of enclosures. Placing a large white or reflective label onto these units did not meet the requirements of the facility or client.

During this project, none of the label alternatives were evaluated for foreign object damage (FOD) because all of the weapon systems involved were either shoulder-fired missiles housed in a mobile launch system or enclosed in the body of the aircraft prior to release. Maintenance facilities considering the use of label alternatives on exposed surfaces of aircraft should examine the FOD impact prior to implementation.

Sustainment facilities such as NADEP JAX, TYAD, and NNSY that repair or refurbish equipment are mainly governed by technical orders that require client approval prior to implementing an alternative. Therefore, if the client resists converting to an approved alternative, a facility could implement very limited conversion to the alternative process.

6.5 LESSONS LEARNED

Early involvement of managers, decision makers, and representatives from government maintenance facilities ensured that all requirements were met and led to early acceptance of the technology.

By identifying a facility that has a definite need, the level of effort required to accomplish a demonstration may be reduced. One facility, after 1.5 years, never proceeded with a demonstration while another facility in need of an alternative achieved implementation within 6 months. More participation may be achieved by targeting a facility that has a need or requires a solution rather than by designating a facility to perform a demonstration.

7.0 REFERENCES

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The following are additional reference sources not called out in this document.

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ESTCP Program Office

901 North Stuart Street
Suite 303
Arlington, Virginia 22203

(703) 696-2117 (Phone)
(703) 696-2114 (Fax)

e-mail: estcp@estcp.org
www.estcp.org